Basal Area Response Nine Years After Fertilizing and Thinning Western Hemlock

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Basal Area Response Nine Years After Fertilizing and Thinning Western Hemlock

by

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ABSTRACT

Dense, closed canopy, immature stands of coastal western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), on northern Vancouver Island, responded well to thinning and, on some sites, to nitrogen fertilization. The best fertilizer net basal area response for the stand (5–18 m^2/ha; 7–28%) was found in thinned stands in the fresh and moist sites; the poorest response (up to 6 m^2/ha; 9%) was observed in the unthinned stands on moderately dry sites. The stand net basal area response to thinning was greatest when the treatment was applied at age 30 than at age 45. After 9 years, none of the thinned stands, either fertilized or unfertilized, had made up the basal area removed in thinnings. However, combining fertilization with thinning accumulated the extra growth produced by fertilization on fewer stems, thus producing a greater amount of valuable wood. Equations are provided for estimating net basal area response.

ACKNOWLEDGEMENTS

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INTRODUCTION

Western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) is one of the most important commercial tree species in coastal British Columbia. Suitability for harvest of immature stands of western hemlock can be accelerated by fertilizing and thinning treatments. Fertilizing with nitrogen (N) boosts tree and stand growth on some sites. Thinning increases merchantable yields per tree by promoting rapid growth on residual stems. However, the magnitude and duration of the response is uncertain in coastal stands of western hemlock. Current practice involves thinning naturally regenerated stands at a stand height of 5–9 m to 600 stems per hectare, or to 800 stems per hectare if a commercial thinning is anticipated. Fertilization is not done operationally.

Research studies (notably the Regional Forest Nutrition Research Project) into the fertilization and thinning of closed canopy stands of western hemlock in the Pacific Northwest suggest that: 1) fertilizer response is inconsistent, highly variable, and possibly negative on some sites; 2) the relationships of the response to stand age and site index are weak or absent; and 3) thinned stands respond better than unthinned (e.g., DeBell 1975; Webster *et al.* 1976; Olson *et al.* 1979; Olson 1980; Gill and Lavender 1983; Radwan and Shumway 1983; Radwan *et al.* 1984; Radwan and DeBell 1989).

In the case of thinning alone, western hemlock is known to respond well to early thinning (Malmberg 1965; Osborn 1968; Dilworth 1980; Hoyer and Swanzy 1986) because of its rapid growth and ability to respond to increased light (Hoyer and Swanzy 1986). Prescriptions for early thinning (at age 10–15 years) favour residual densities of between 740 and 1100 stems per hectare (e.g., Dilworth 1980). Commercially thinned stands of western hemlock do not respond significantly in the absence of earlier density control (Omule 1988).

This report addresses several questions about the fertilization and thinning of dense, closed canopy, immature stands of western hemlock on Vancouver Island, B.C.: (1) What is the magnitude and duration of net basal area response? (2) What effect do fertilizer dosage and percent basal area removed have on the response? (3) How does treatment response vary with stand age, basal area, and site index at time of treatment?

The report is based on 9-year remeasurement data from Experimental Project (EP) 703, of the B.C. Ministry of Forests, Research Branch. It is the largest single study undertaken in British Columbia on the impact of silvicultural practices on tree and stand growth and yield.

METHODOLOGY

Study Design

The EP 703 study was initiated to measure the growth response of coastal western hemlock and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) to thinning and nitrogen fertilization. The methodology is described in detail by Darling and Omule (1989). The study consists of 85 installations (940 plots), located in immature stands of Douglas-fir and western hemlock of various ages and ecological conditions in coastal British Columbia (Figure 1), established from 1971 to 1975. This report is based on 16 installations (220 plots) located in pure (greater than 80% by volume) naturally regenerated stands of western hemlock in the submontane variant of the very wet maritime Coastal Western Hemlock (CWHvm) subzone.[1]

The treatments were N fertilization and thinning, in a factorial arrangement (Figure 2). Fertilizer dosages ranged from 0 to 900 kg N/ha, and the thinning removed 0–50% of the initial basal area in an experimental unit. Each experimental unit was a square 0.05-, 0.07-, or 0.10-ha plot. The number of plots per installation ranged from 4 to 32. Nitrogen in the form of prilled urea (46% N) was applied by hand over the plot and buffer in the fall or early spring before thinning. The thinning was a modified crown thinning, which favoured dominant and co-dominant trees. The d/D ratio (mean dbh of cut trees/mean dbh of all trees) ranged from 0.80 to 0.90.

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[1] K. Klinka, J. Pojar, and D. Meidinger. Revision of zonal classification in coastal British Columbia. Manuscript accepted for publication in Northwest Science.

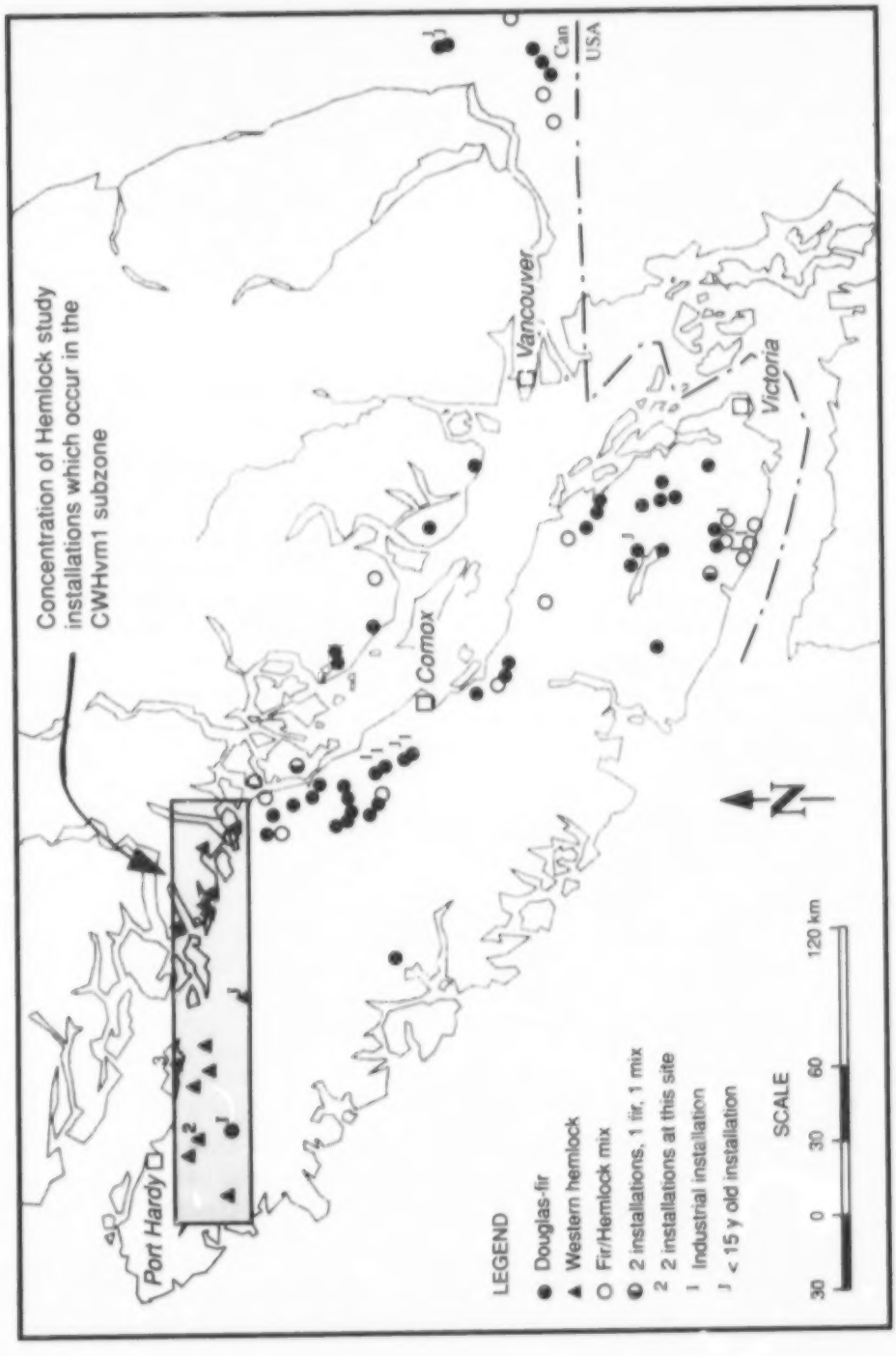


FIGURE 1. Approximate location of the 85 installations for EP 703.

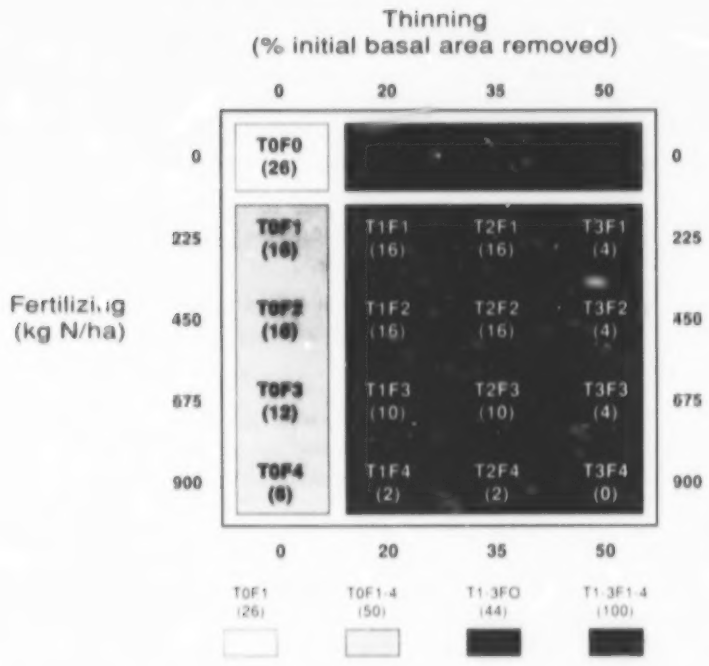


FIGURE 2. Treatment definitions for EP 703. In the figure, T stands for thinning, F stands for fertilization, and the numbers following each letter are treatment-level serial numbers. Values in brackets indicate the number of plots in pure western hemlock. TOFO, T1-3FO, TOF1-4, and T1-3F1-4 are labels for the following treatment categories: untreated (control), thinned only, fertilized only, and combined thinned and fertilized, respectively.

The Data

The data used included plot basal area, number of stems, site index, and total age. Net basal area per hectare of live trees, excluding ingrowth, was calculated for the entire-stand and prime-tree populations from tree dbh measurements for each plot before and after treatment, and 3, 6, and 9 years later. Prime-tree summaries apply to the 250 trees per hectare of largest dbh 9 years after treatment.[2] The growth of 13, 18, and 25 live trees per 0.05-, 0.07-, and 0.10-ha plot, respectively, was traced back to the time of treatment. Site index was estimated according to the site curves of Hegyi *et al.* (1979), based on total age 50 years. Total age was estimated from increment cores of a subsample of trees measured for height in each plot.

Frequency distribution of plots by initial basal area, site index, and total age is depicted in Figure 3. Development of number of stems relative to average diameter for each plot and treatment category is depicted in Figure 4.

[2] The most valuable trees expected at final harvest are now referred to as "prime trees" rather than "crop trees" in this sense because more than 250 trees per hectare will comprise the final harvest or crop (K.J. Mitchell, Research Branch, pers. comm., June 1990).

Data Analysis

Treatment responses were quantified by stand attributes at time of treatment, based on two-stage regression analysis (West *et al.* 1984) of the stand and prime-tree net basal area.[3] A regression approach was used because the study design was unbalanced (Darling and Omule 1989, p. 3) and measurements were not taken at the same points in time in all the plots. Two-stage regression analysis was used to reduce the possible effects of the serial correlation inherent in the repeated measurements in the plots.

The following three-step procedure for fitting equations was used to predict stand and prime-tree cumulative and annual response for each of three treatment categories: fertilizing alone (T0F1-3), thinning alone (T1-3F0), and combined fertilizing and thinning (T1-3F1-3):

1. Equations were fitted to estimate net basal area, *BA*, in the unfertilized, unthinned (control) plots (T0F0), as functions of time since plot establishment (X) and stand attributes at plot establishment:

   $\hat{BA} = f$(total age; initial basal area; site index; X)

2. Cumulative response, R, for each treatment category was calculated in each treated plot and measurement period as the difference between the observed net basal area of the treated plot and its predicted net basal area as an untreated plot having the same initial (pre-treatment) stand attributes (Figure 5):

   R = treated plot net basal area – $\hat{BA}$

   The equation in step 1 was used to predict how the net basal area would have developed in the treated plots had they not been fertilized or thinned. For the thinned plots, the amount of basal area removed was added to the observed net basal area before the difference was calculated.

3. Equations were then fitted to the cumulative responses calculated in step 2, to estimate cumulative response in the treated plots as a function of X and initial stand attributes:

   $\hat{R} = f$(total age; initial basal area; site index; X)

   The resulting cumulative response equations were differentiated with respect to X to estimate annual response, r:

   $\hat{r} = d\hat{R}/dX$

   That is, annual response is the difference between the net basal area annual growth of treated plot and its net basal area annual growth as an untreated plot.

Graphs and tables generated from the response equations in step 3 were used to interpret the response to treatment.

The plots were sorted by predicted cumulative net basal area response after 9 years and by biogeoclimatic site units (Klinka *et al.* 1984, p. 110), to identify potential sites to fertilize and thin.

---

[3] Fertilizer and thinning responses were based on stand basal area rather than on volume to avoid errors resulting from inadequate and inconsistent sampling for tree heights (Darling and Omule 1989, p. 16). However, as pointed out by R.O. Curtis (in Omule 1990, p. 3), it may be risky to substitute basal area for volume because, in general, basal area and volume responses are not equivalent and may be notably different in certain instances.

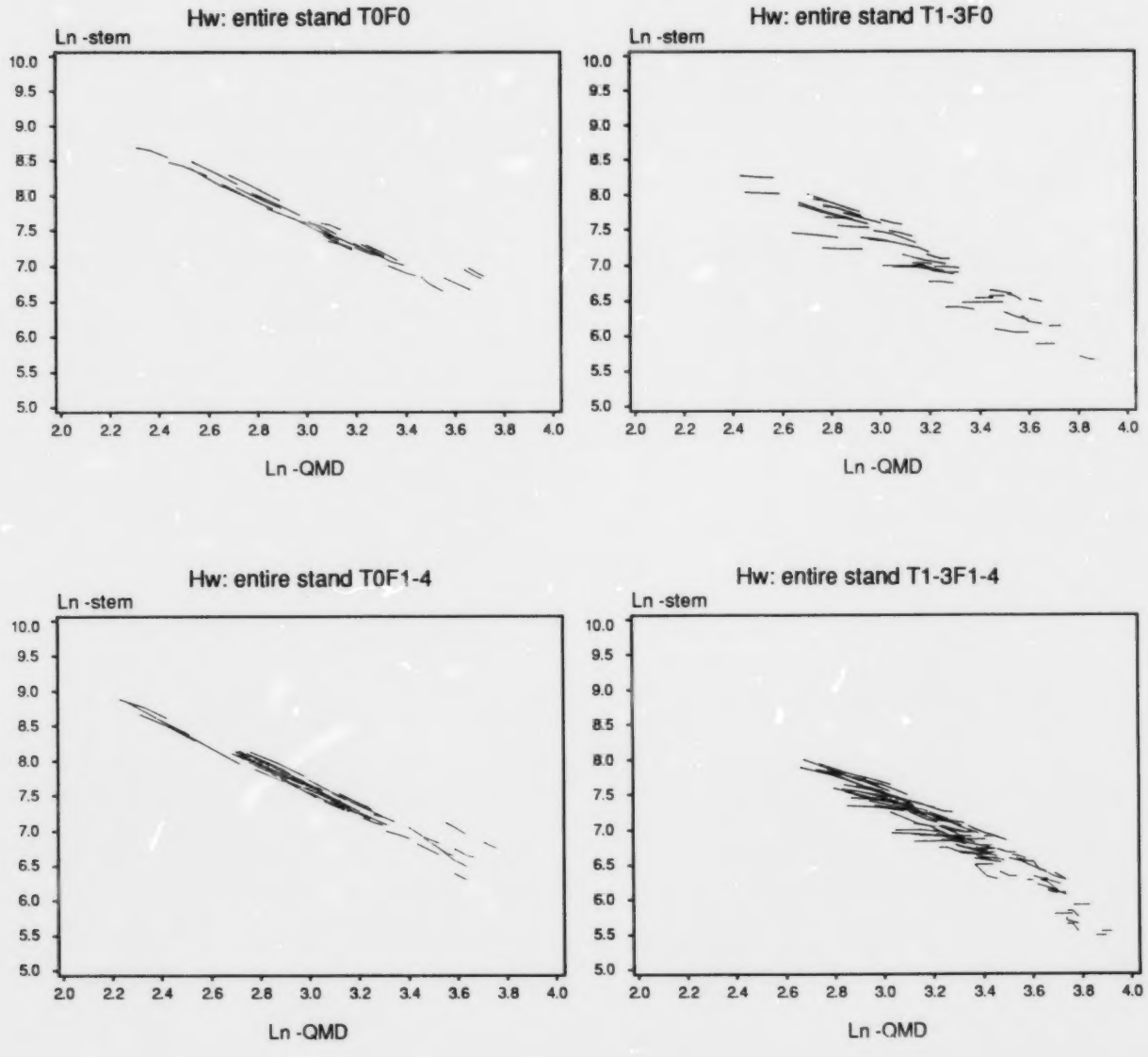


FIGURE 3. Relationship of stem count to average diameter for western hemlock (Ln = natural logarithms).

FIGURE 4. Frequency distribution of study plots by initial stand attributes.

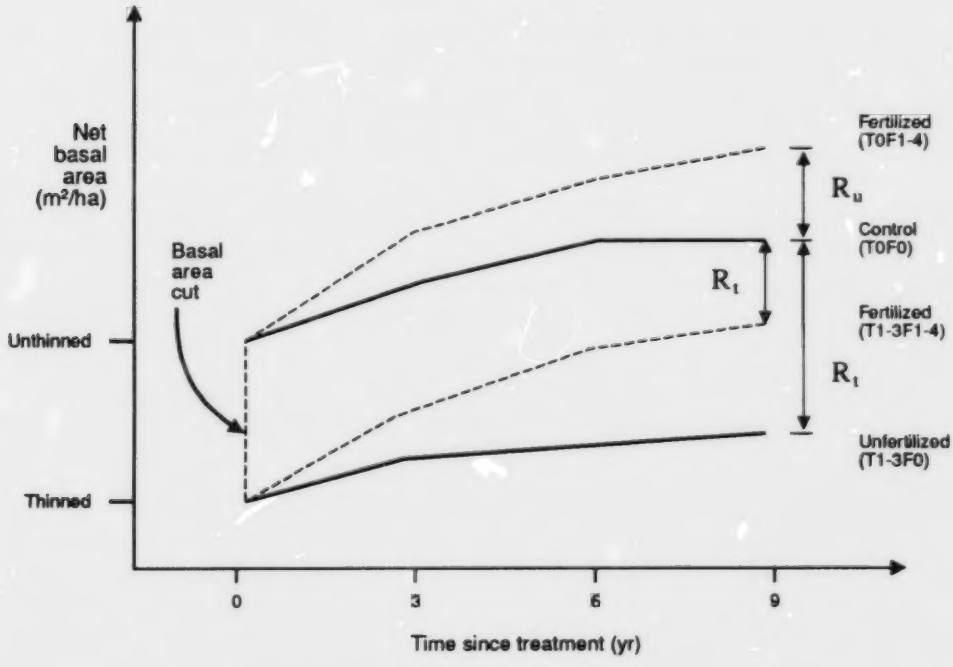

Net basal area (m²/ha)
Basal area cut
Unthinned
Thinned
Fertilized (T0F1-4)
Control (T0F0)
Fertilized (T1-3F1-4)
Unfertilized (T1-3F0)
Time since treatment (yr)
For the unthinned plots, cumulative response, c.r. = Ru.
For the thinned plots, cumulative response, as defined in text, c.r. = difference between treated and control b.a.= Rt + basal area cut.

FIGURE 5. Definition of treatment response.

RESULTS

Equations for estimating net basal area response of coastal western hemlock to specific fertilization and thinning treatments are presented in Appendix [1]. The equations have also been assembled into a PC-based empirical simulator called EP703:SIM, which is available upon request from the senior author. Their use requires knowledge of initial basal area, number of stems, site index, and total age, as well as of fertilizer dosage and percent basal area removed. They can be used to calibrate and validate growth models, and to assist in the evaluation of potential stands for treatment.

A list of plots, ordered by stand predicted cumulative response and treatment category, indicates that about 60% of the unthinned plots responded positively to fertilizing with N; and that most of the thinned, unfertilized plots and combined thinned and fertilized plots also responded positively to treatment (Appendix 2). The list may be useful for identifying those sites and stands that will respond well to N fertilization. For example, the unthinned plots located in the fresh and moist (HwBa-Blueberry and HwBa-Deer fern) sites responded to fertilization better than did those in the moderately dry (HwCw-Salal) sites, taking into account differences in stand age. Thinned stands on the moderately-dry sites, however, also responded well to fertilization. Differences in response among sites were probably due to differences in the amount of moisture, as all the sites were classified as nutrient poor to medium in these examples. Note that confidence in the use of the list as a site selection guide is limited because of the small sample size in each treatment-site unit category.

DISCUSSION

On average, the net basal response of closed canopy stands of western hemlock to fertilization was generally low and variable, compared to the response of Douglas-fir reported by Omule (1990). The low magnitude and high variability in western hemlock response to fertilization may be due to genetic variability among trees, inherent differences among sites in N deficiency, the presence of other limiting nutrients, and the toxicity of urea N (Olson *et al.* 1979; Gill 1981; Gill and Lavender 1983; Radwan and Shumway 1983; Radwan *et al.* 1984; Radwan and DeBell 1989). Research studies should be undertaken to explain more fully the factors controlling the response of western hemlock to N fertilization.

Competition before plot establishment, for instance, might confound the response to thinning and fertilization. The relationships of response to initial stand attributes might also be confounded by the relatively small range of site and stand conditions in the data, and the possible association between such initial stand attributes as site index and total age (Figure 4).[4]

Nine-year net basal area average response among treatment levels is compared below by treatment category. The average responses are based on the following initial stand attributes: total age 30 years, site index 30, basal area 56 m^2/ha, and stem count 4521 stems per hectare.

Unthinned, Fertilized Stands (T0F1-4)

The cumulative response of the stand (–3.5 m^2/ha; –5%) and prime trees (–0.6 m^2/ha; –4%) to application of 225 kg N/ha was negligible after 9 years. The unthinned stands were probably close to an upper density limit (Figure 3), and any acceleration of growth produced by fertilizer would be expected to increase basal area and mortality with relatively little change in net stand basal area. Also, poor light conditions and moisture stress may have resulted in poor use of the added N.

---

[4] Changing site curves from those of Hegyi *et al.* (1979) to Wiley's (1978) should diminish or even eliminate the site-age correlation that is apparent in Figure 3, because site index will increase for plots less than index age and decrease for plots greater than index age (I.R. Cameron, B.C. Min. For., pers. comm., June 1990). Wiley's (1978) site curves are now recommended for use in British Columbia (Mitchell and Polsson [1988]).

Increasing the fertilizer dosage from 225 kg N/ha to 900 kg N/ha slightly increased stand response to -1.5 m^2/ha (-2%), but did not affect prime-tree response (Tables 1 and 2).

Average annual stand response at all fertilizer dosages declined from about 0.2 m^2/ha per year after 3 years to about -0.5 m^2/ha per year after 9 years (Figure 6). Annual stand response for all thinning levels was slightly higher when treatment was applied at age 45 than at age 30 (Figure 7). The relationship of annual prime-tree response to initial age and site index was not noticeable, however.

Thinned, Unfertilized Stands (T1-3F0)

The cumulative response for the stand (7.0 m^2/ha; 11%) and prime trees (1.0 m^2/ha; 6%) was about the same for all thinning levels after 9 years. The 9-year cumulative response was not enough to restore the basal area removed in thinnings, and the net basal area in the thinned stands continues to lag behind that in the unthinned stands (Figure 8).

The stand response is the result of a combination of: actual growth of comparable trees in the thinned stands relative to the unthinned; slower growth on many more small trees in the unthinned stands; and greater mortality of smaller-than-average trees in the unthinned stands relative to the thinned.

Annual stand response magnitude and duration were about the same for all thinning levels. On the average the annual response increased from about .80 m^2/ha per year to about 1.5 m^2/ha per year, over the 9-year period (Figure 9). Annual stand response at all thinning levels was slightly higher when treatment was applied at age 30 on site 35 than at age 45 or on site 25 (Figure 10). The relationship of annual prime-tree response to initial age and site index was not noticeable, however.

Thinned, Fertilized Stands (T1-3F1-4)

The cumulative response of the stand and prime trees to combined fertilizing with 225 kg N/ha and thinning were generally higher than the responses to fertilizing alone or to thinning alone. Additional response from fertilizing thinned stands ranged from about 2 to 7 m^2/ha after 9 years (Table 1). The cumulative response increased slightly with increase in percent basal area removed, and it was generally little affected by increases in fertilizer dosage (Tables 1 and 2).

The stand response was not enough to restore the basal area removed in thinnings to the level of that in the unthinned stands over the 9-year period (Figure 8). However, combining fertilization with thinning, the extra growth produced by fertilization is accumulated on fewer stems, which will produce a greater amount of valuable wood. For example, combining fertilization with thinning allocates 27–35% of the net basal area into prime trees, whereas fertilizing alone or no treatment allocates only about 24% into prime trees (Table 3).

Annual stand response duration for all combined thinning and fertilizer levels were virtually identical, but the magnitudes increased with increase in percent basal area removed (Figure 11). The relationships of annual stand and prime-tree responses to initial age and site index, for a given initial basal area, could not be detected, except for annual stand response which was slightly higher on site 35 than on site 25 (Figure 12).

TABLE 1. Entire stand predicted cumulative response (absolute, %) over a nine year period

	T0		T1		T2		T3	
F0	0.00	0.0	7.37	11.4	6.98	10.8	6.74	10.4
F1	-3.51	-5.4	9.42	14.5	12.02	18.5	13.98	21.6
F2	-2.86	-4.4	9.32	14.4	11.91	18.2	13.72	21.2
F3	-2.18	-3.4	9.22	14.2	11.79	18.2	13.72	21.2
F4	-1.49	-2.3	9.11	14.1	11.67	18.0	-- --	-- --

Left column = Absolute response (m^2/ha).
Right column = Percent (%).
Initial age = 30 years.
Site index = 30.
Preliminary Basal area = 55.73 m^2/ha.
Preliminary Stem count = 4521.47 stems/ha.
Initial Basal area of Prime trees = 11.2 m^2/ha.

TABLE 2. Prime tree predicted cumulative response (absolute, %) over a nine year period

	T0		T1		T2		T3	
F0	0	0.0	1.11	7.1	1.02	6.5	0.92	5.9
F1	-.56	-3.6	1.01	6.4	0.92	5.8	0.82	5.3
F2	-.56	-3.6	0.91	5.8	0.82	5.2	0.73	5.3
F3	-.56	-3.6	0.81	5.2	0.72	4.6	0.63	4.0
F4	-.56	-3.6	0.71	4.5	0.62	4.0	-- --	-- --

TABLE 3. Prime tree predicted yield as a percentage (%) of the Entire Stand yield nine years after treatment

	T0	T1	T2	T3
F0	24.2	28.4	34.0	42.5
F1	24.6	27.2	30.7	35.6
F2	24.4	27.1	30.6	35.4
F3	24.1	27.0	30.4	35.4
F4	23.9	26.9	30.3	----

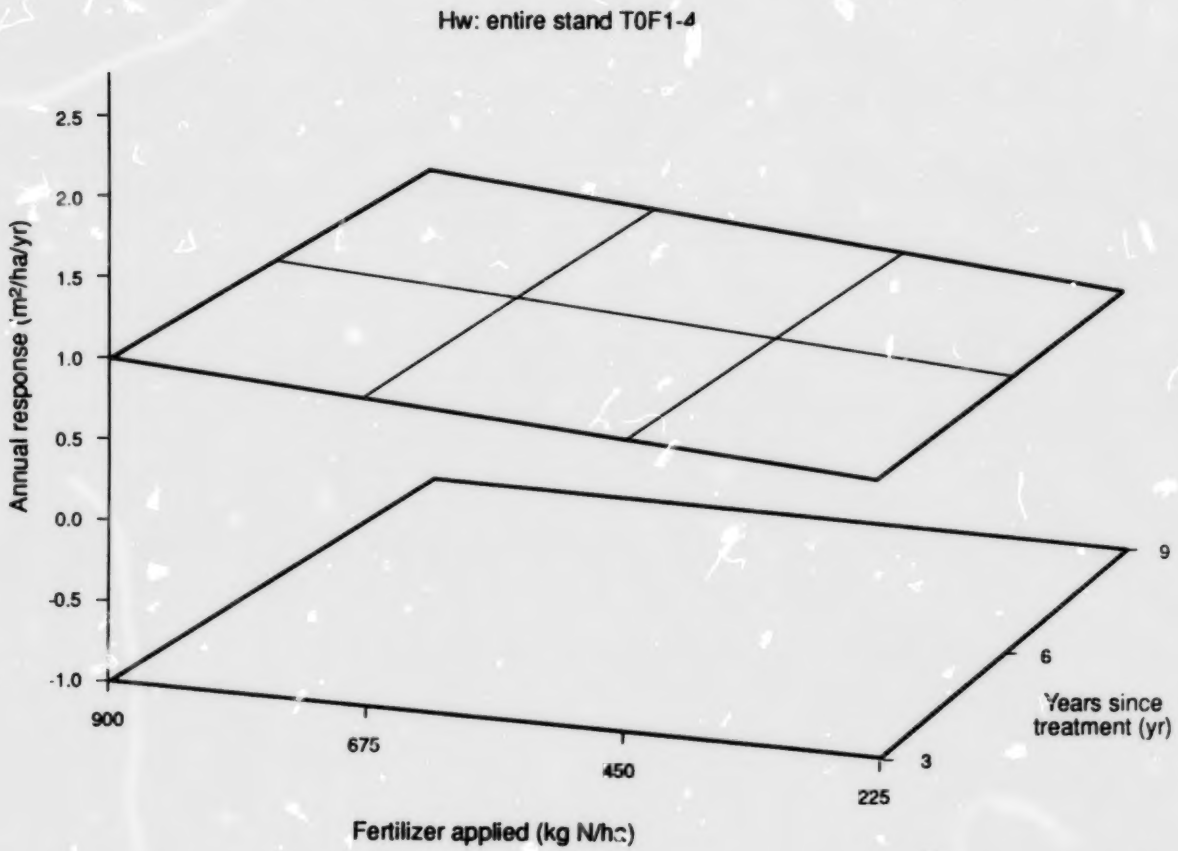


FIGURE 6. Predicted annual response for the unthinned, fertilized stands.

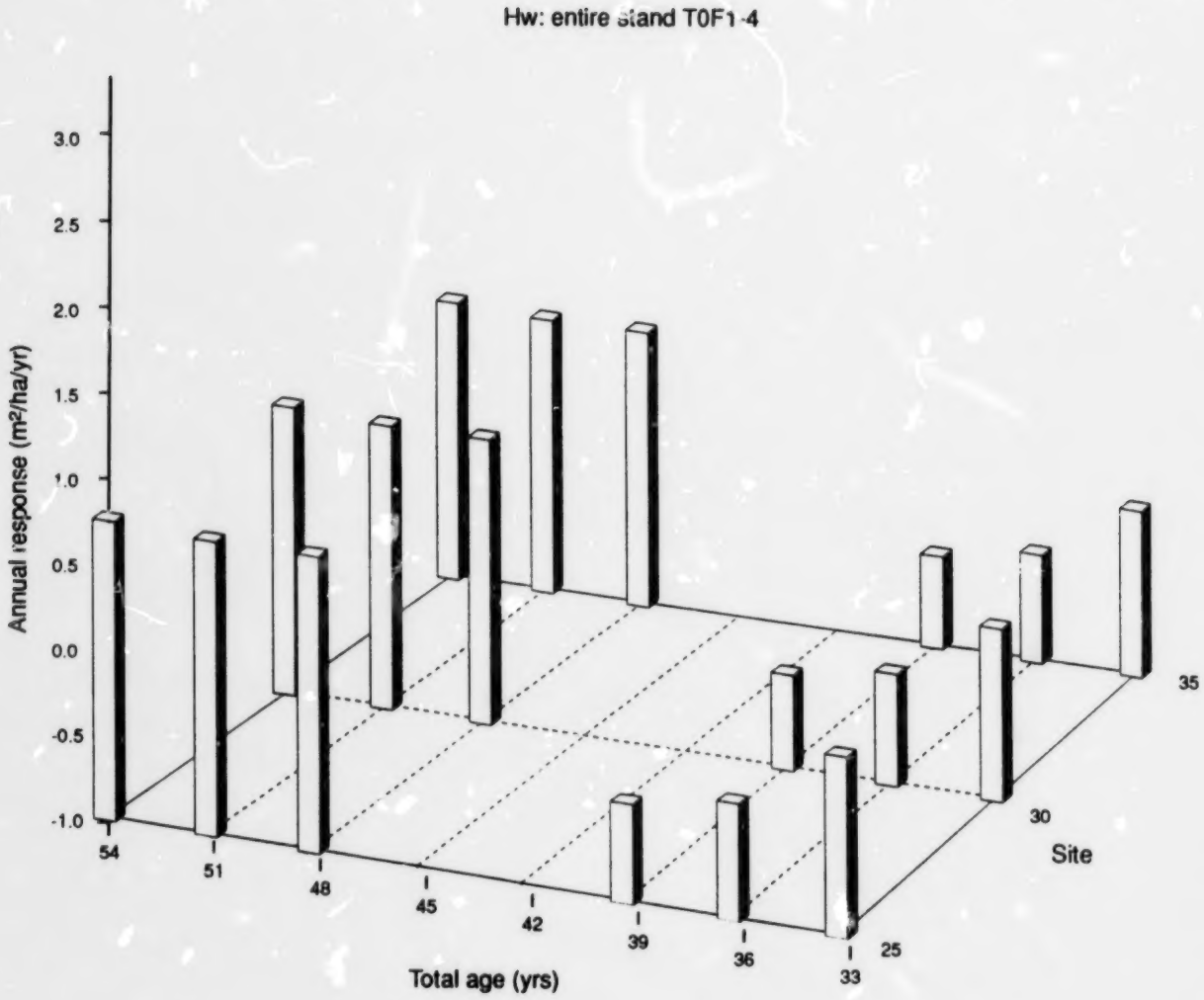


FIGURE 7. Relationship of predicted annual response to stand age for the unthinned, fertilized stands.

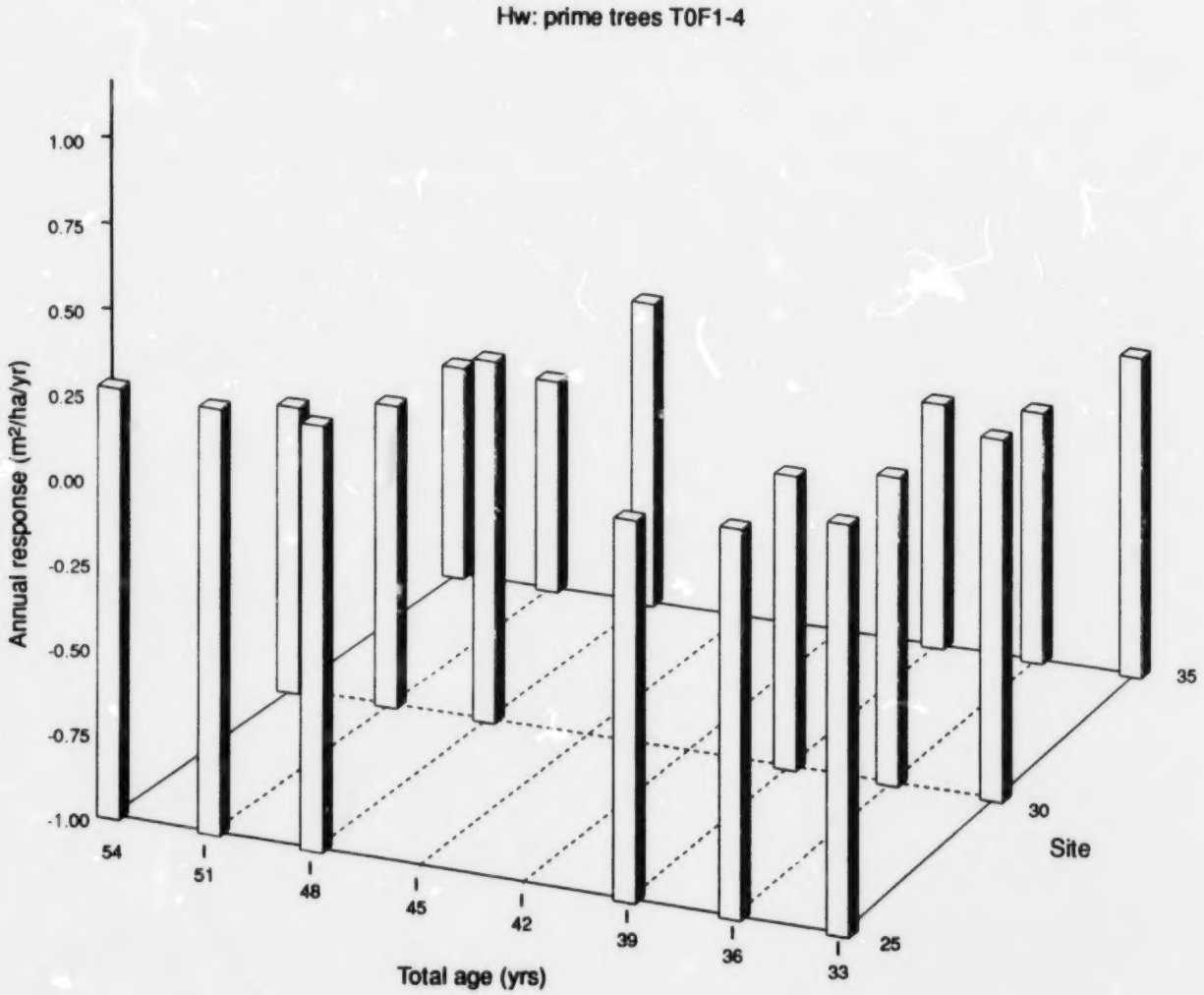


FIGURE 7. *Continued.*

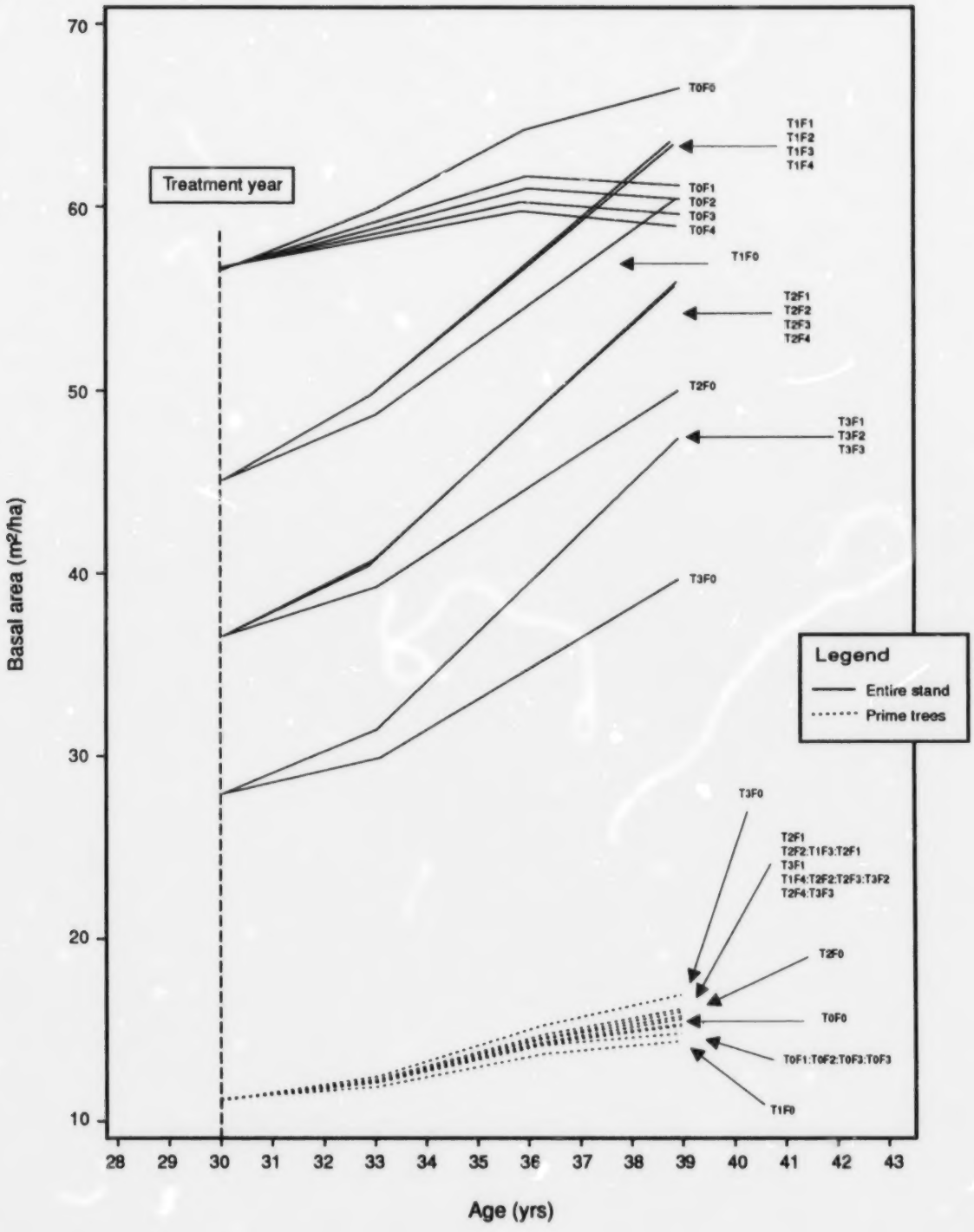


FIGURE 8. Development of predicted stand net basal area by treatment.

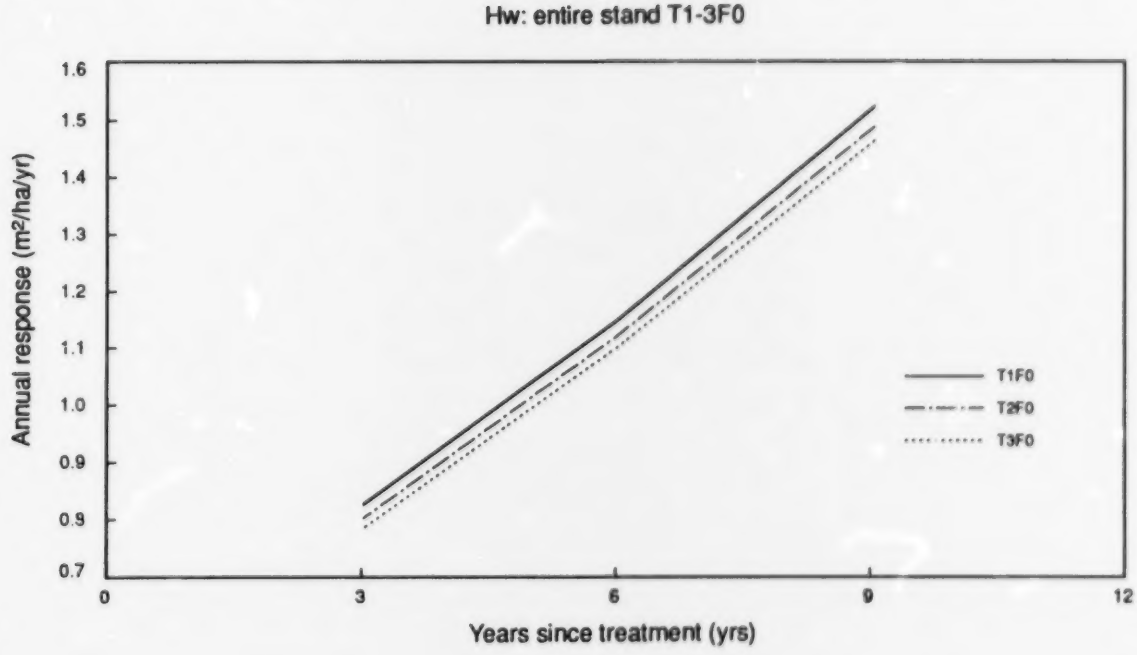


FIGURE 9. Predicted annual response for the thinned, unfertilized stands.

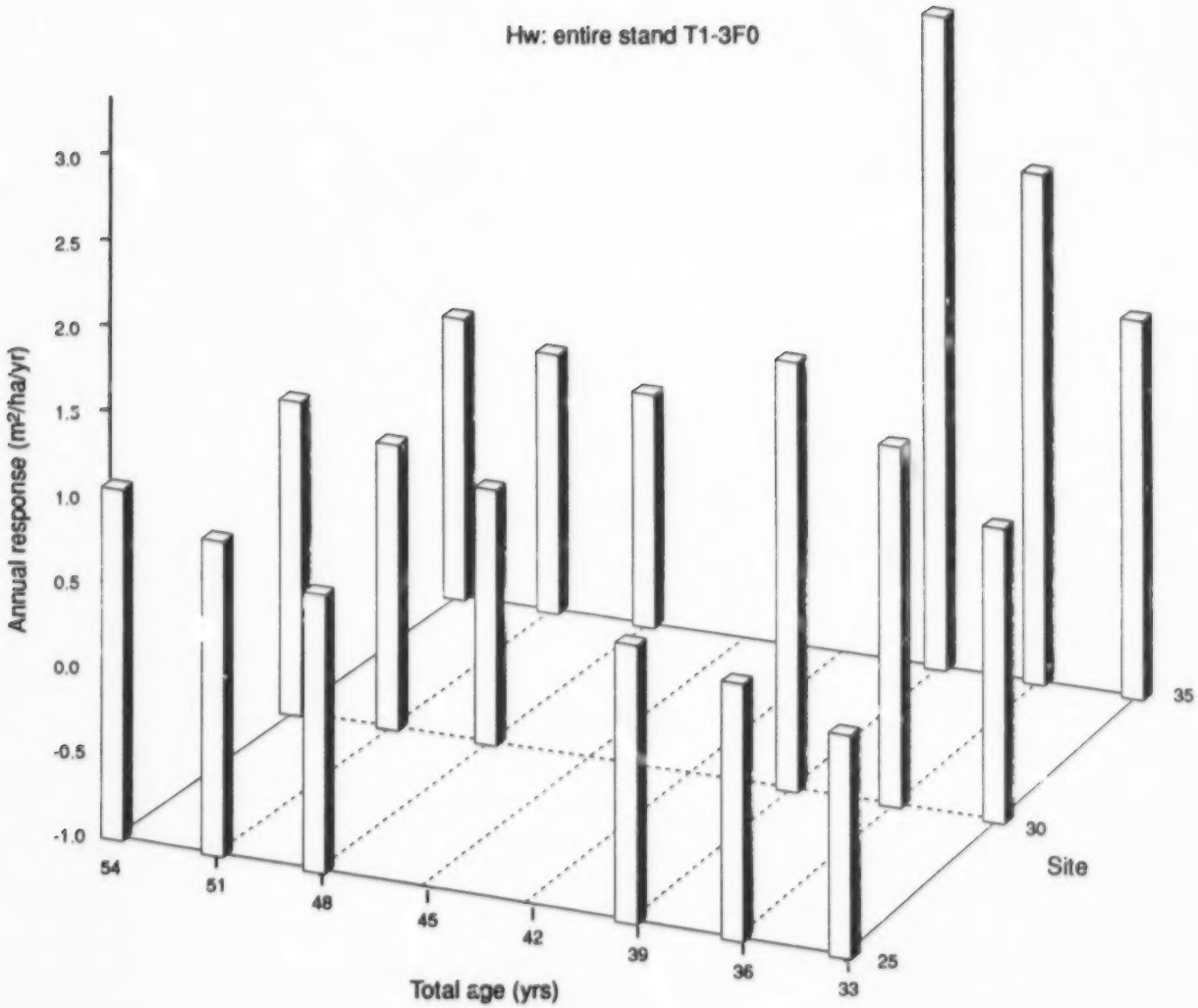


FIGURE 10. Relationship of predicted annual response to stand age for the thinned, unfertilized stands.

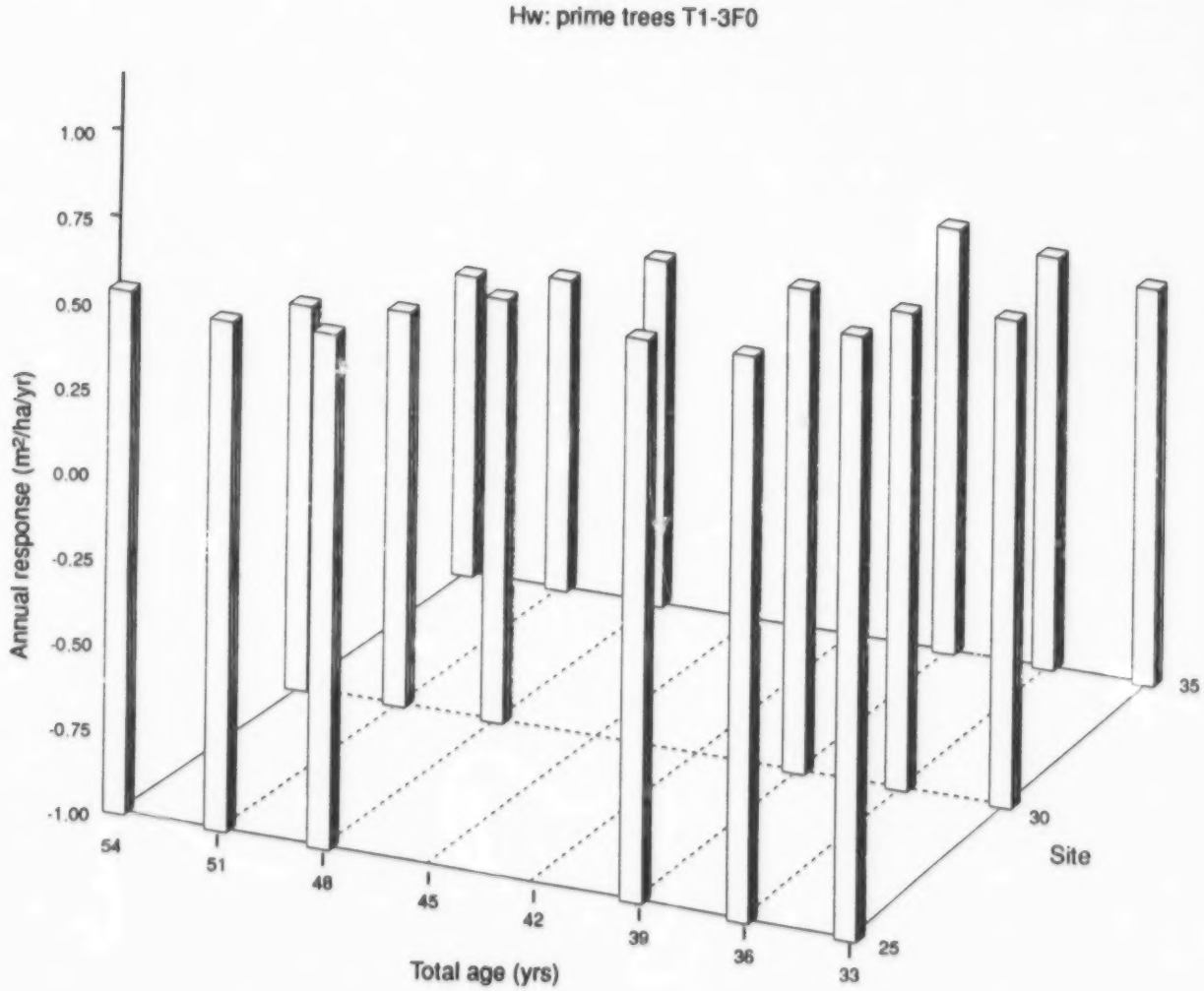
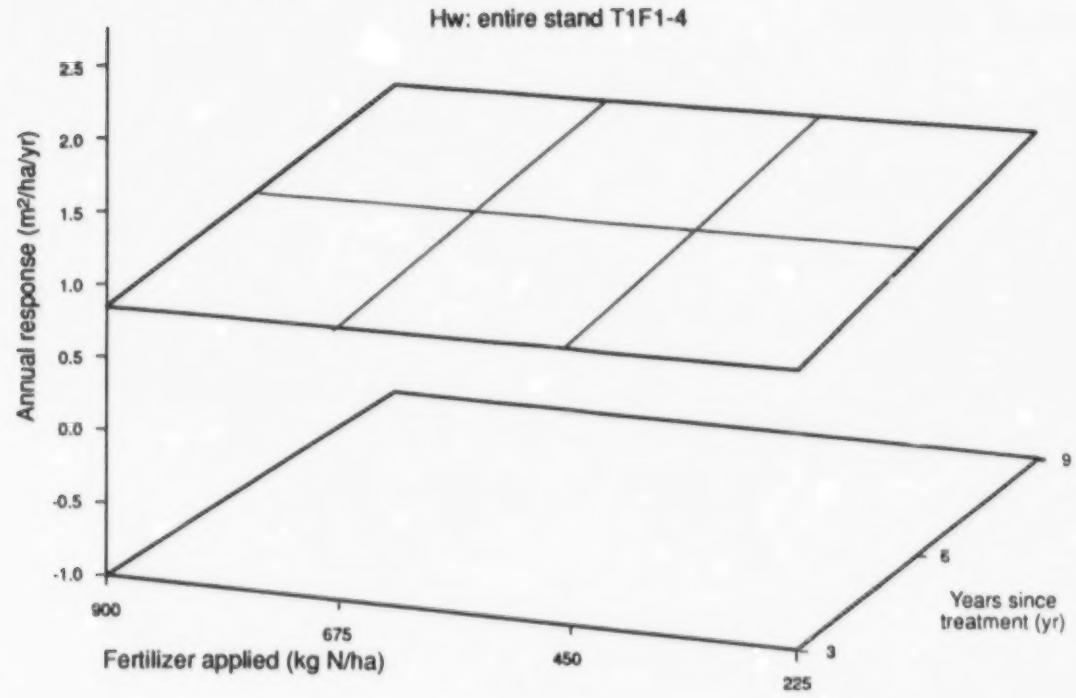


FIGURE 10. *Continued.*



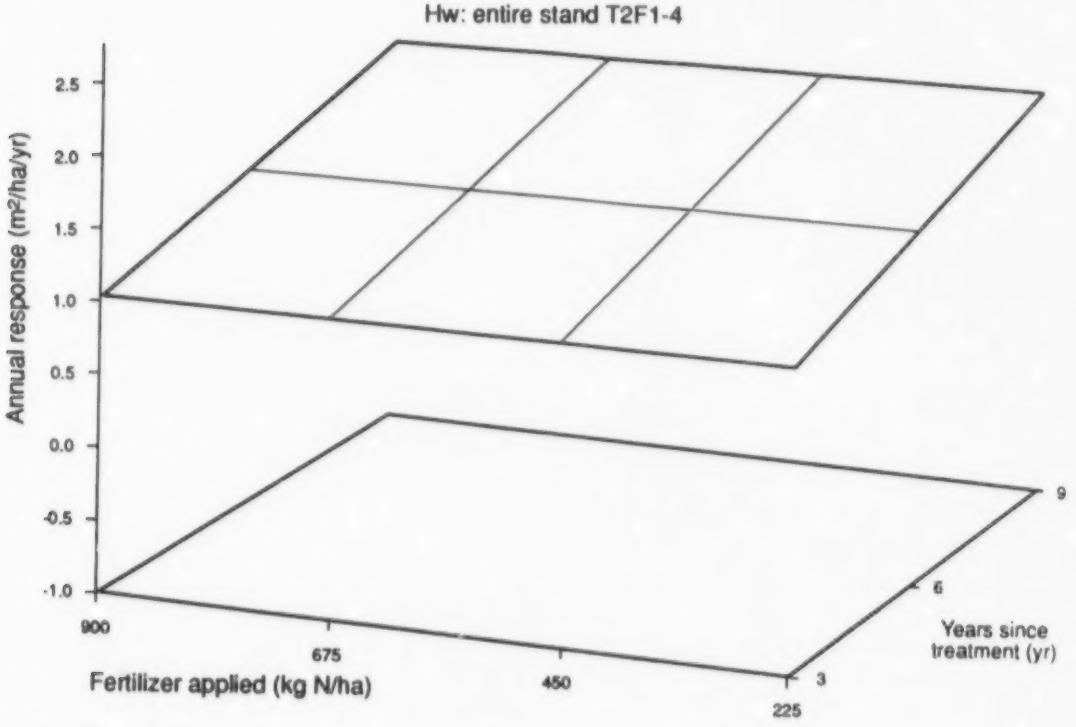


FIGURE 11. Predicted annual response for the thinned, fertilized stands.

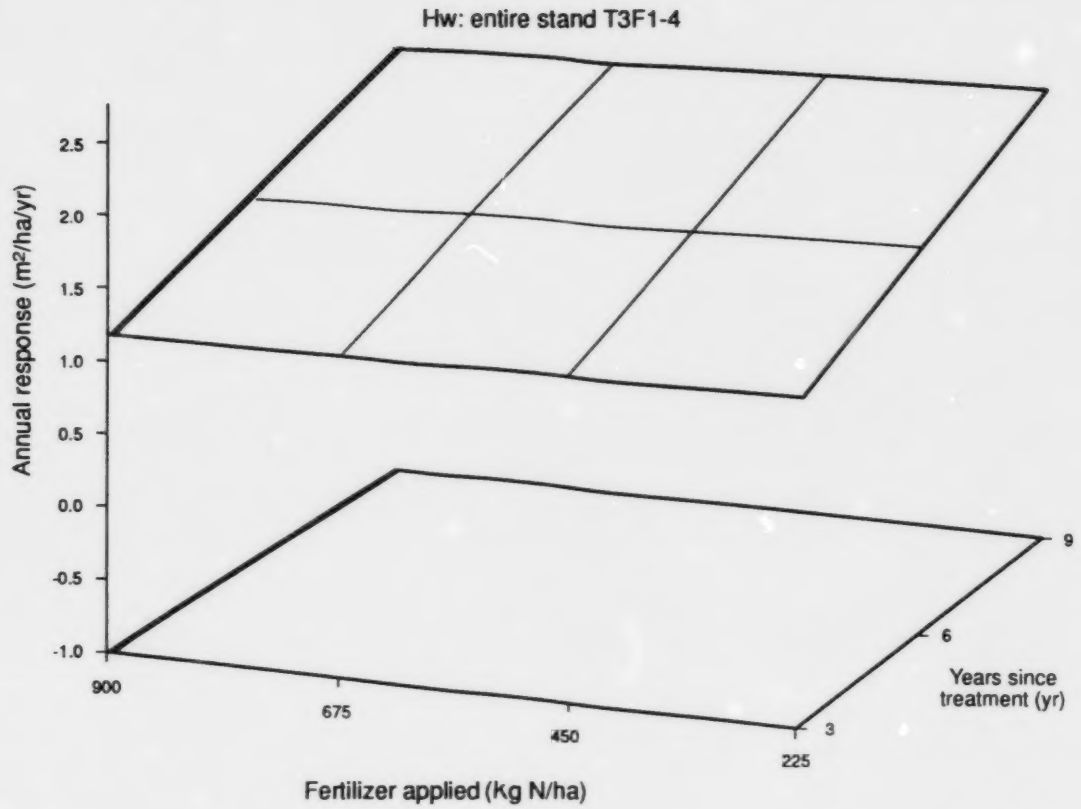


FIGURE 11. *Continued.*

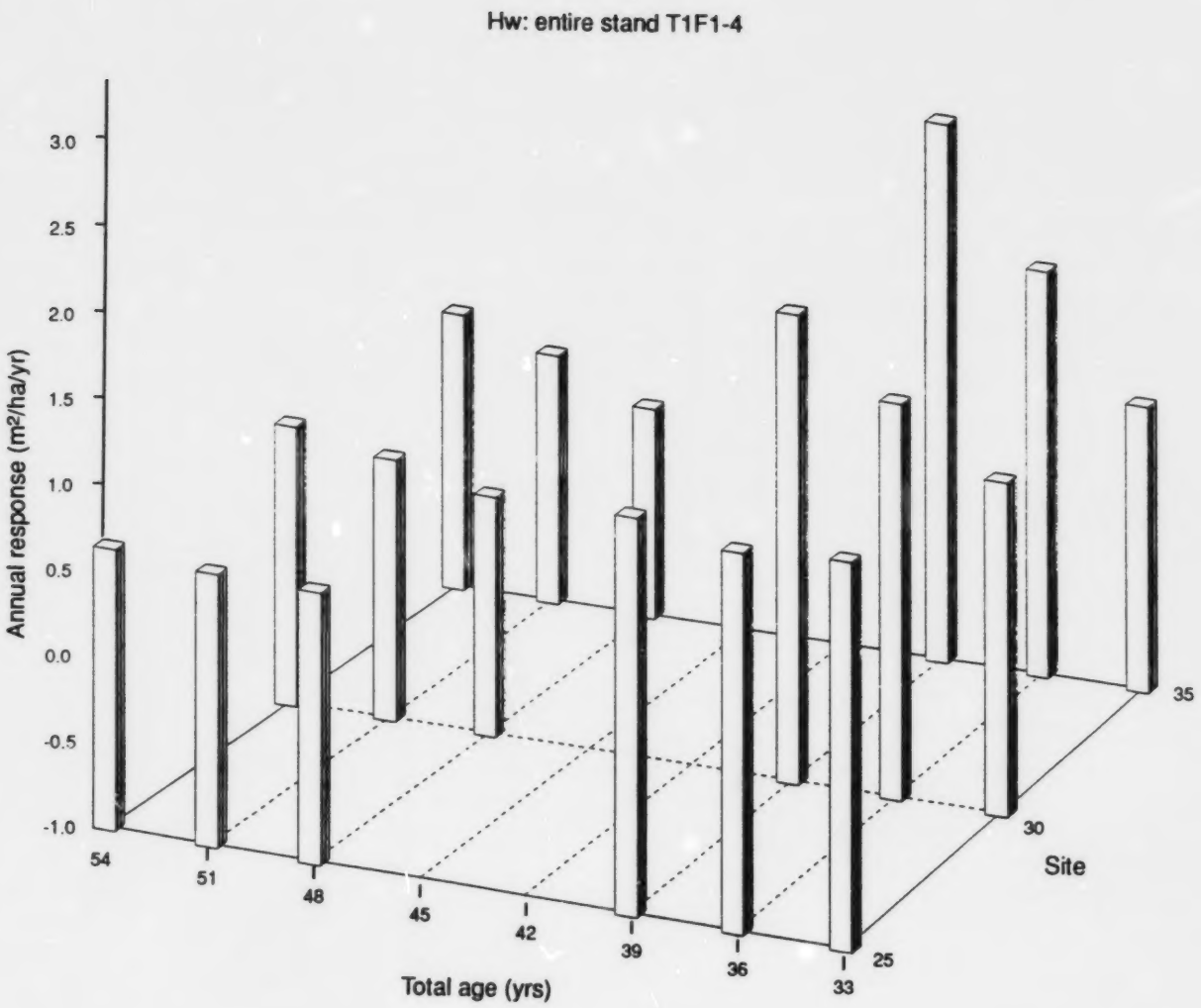


FIGURE 12. Relationship of predicted annual response to stand age for the thinned, fertilized stands.

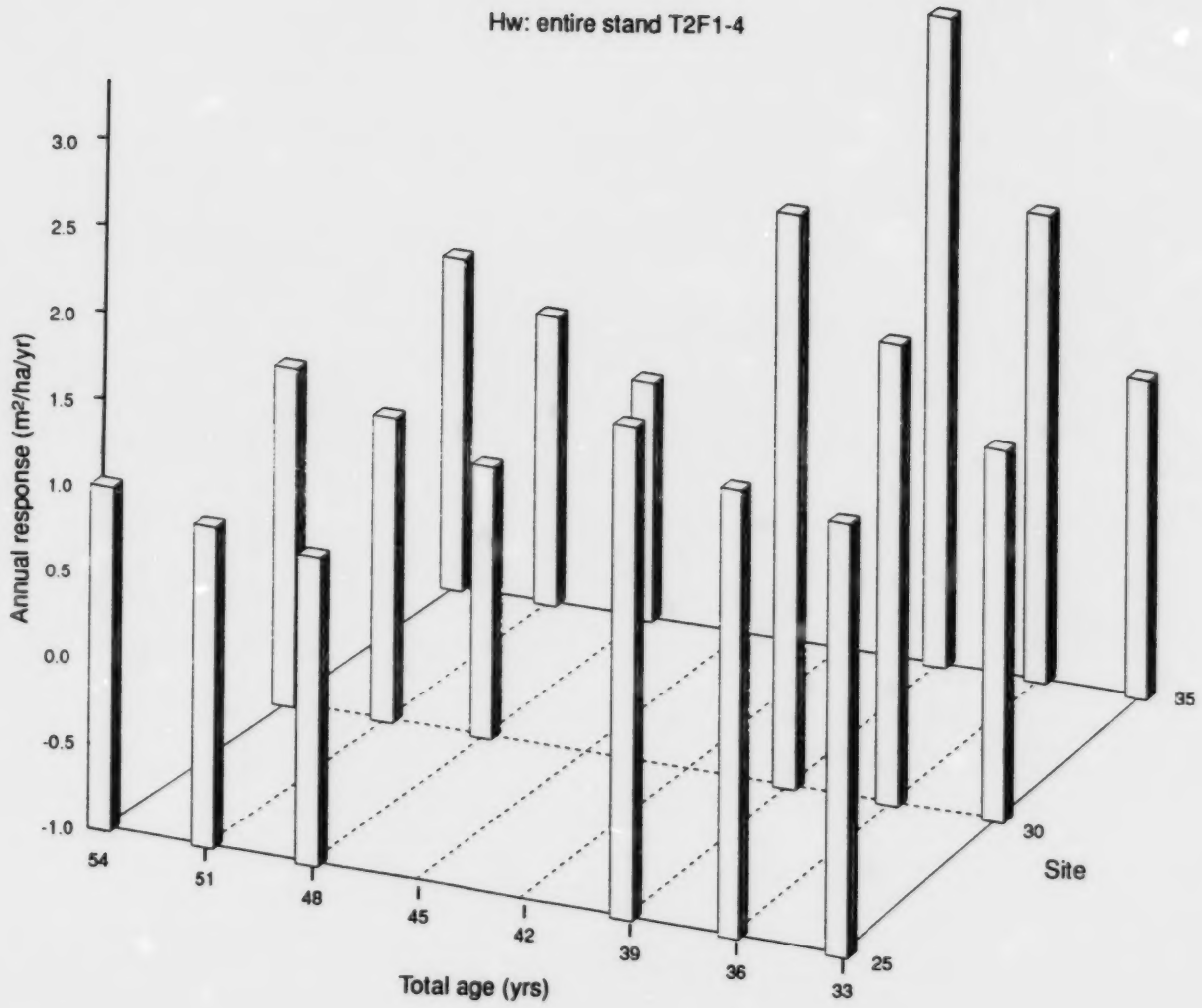


FIGURE 12. *Continued.*

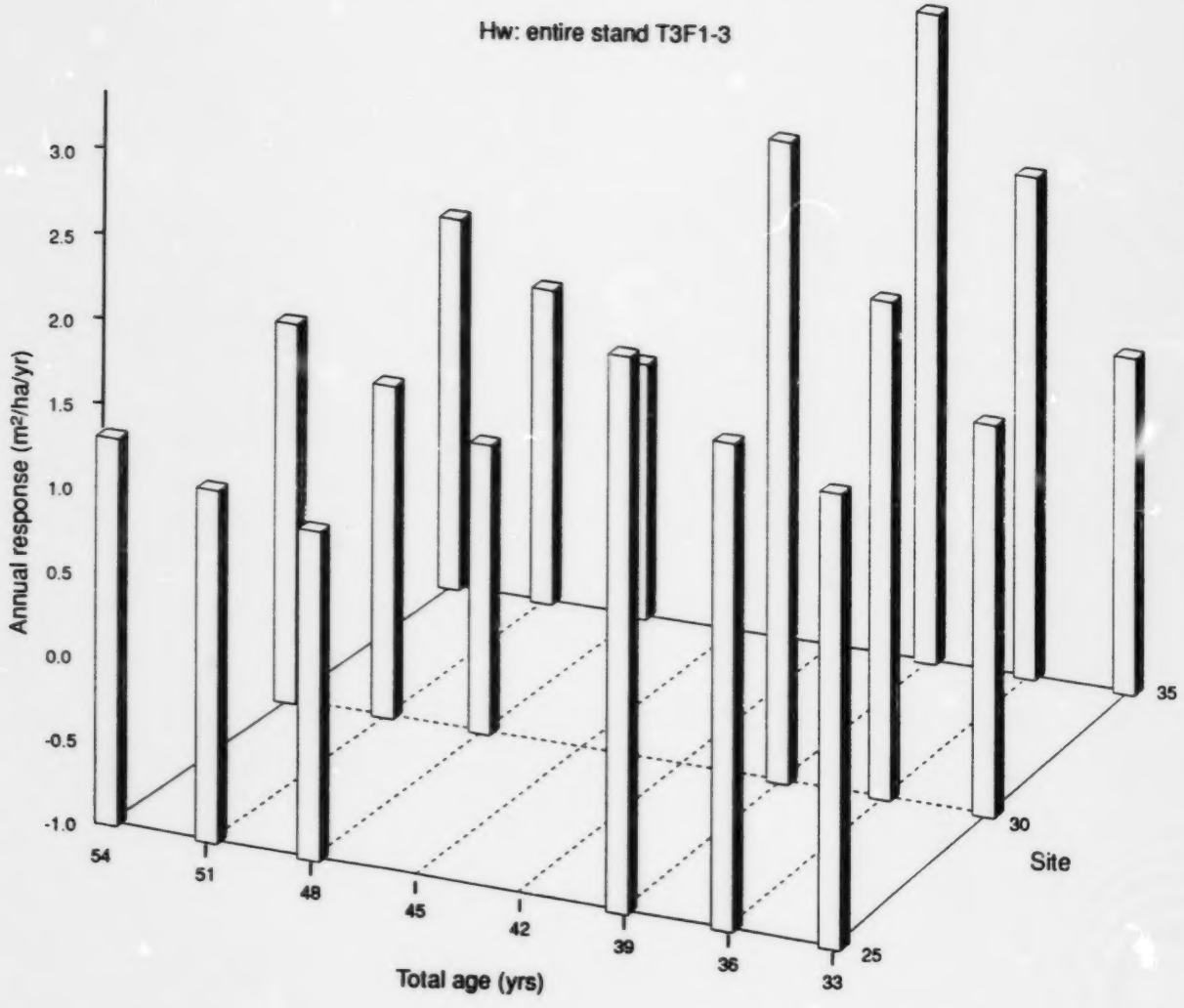


FIGURE 12. *Continued.*

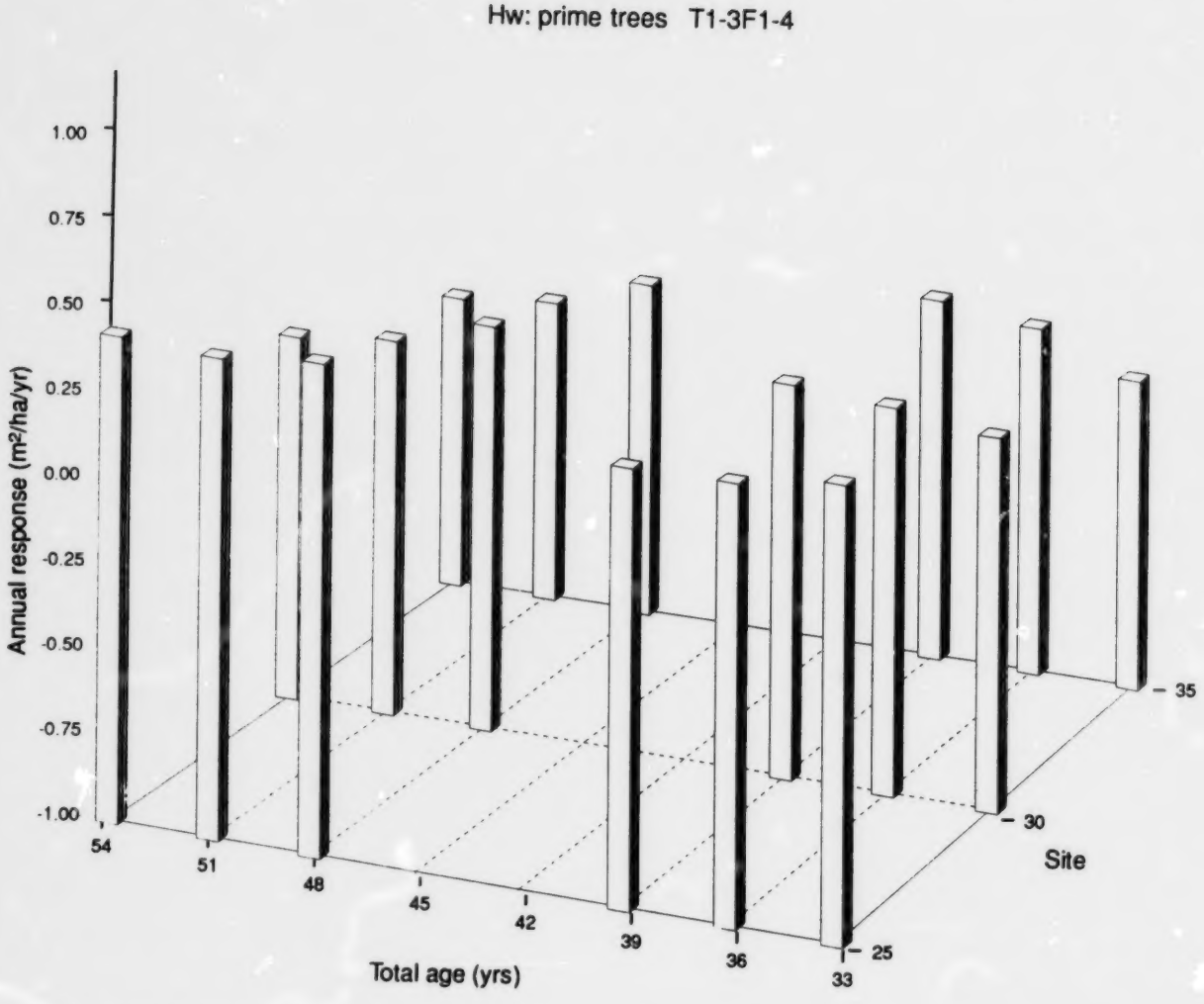


FIGURE 12. *Continued.*

SILVICULTURAL OPPORTUNITIES

The following observations made from the study may be helpful to the forest manager who must decide whether to fertilize or thin a given stand of western hemlock in the submontane variant of the CWHvm subzone:

1. The best fertilizer stand net basal area response (5–18 m^2/ha; 7–28%) was found in thinned stands in the fresh and moist sites; the poorest net basal area response (up to 6 m^2/ha; 9%) was observed in the unthinned stands on moderately dry sites (Appendix 2).
2. The stand net basal area response to thinning alone was greatest when the treatment was applied at age 30 than at age 45. The prime-tree net basal area response to thinning alone was greatest following removal of 50% of initial basal area (Figure 8).
3. After 9 years, none of the thinned stands, either fertilized or unfertilized, had made up the basal area removed in thinnings. However, combining fertilization with thinning, the extra growth produced by fertilization accumulated on fewer stems, thus producing a greater amount of valuable wood.

The decision to treat a stand, however, will depend upon several other factors not dealt with here, such as the economics of the fertilization and thinning, the need to overcome irregularities and shortages in wood supply, and the need to increase or sustain employment.

CONCLUSIONS

The following conclusions, in the form of answers to the questions posed in the introduction, are based on net basal area. They are applicable within the range of site and stand conditions of the western hemlock plots of the EP703 study.

- Cumulative response of unthinned stands of western hemlock to fertilizing with 225 kg N/ha was negligible (–3.5 m^2/ha; –5%). It does not appear to be beneficial to add any more fertilizer than 225 kg N/ha.
- Cumulative response of the stand to thinning alone (20% basal area removed) was significant (7.4 m^2/ha; 11%). Increasing the percent basal area removed did not affect the response.
- Cumulative response of the stand to combined fertilizing with 225 kg N/ha and thinning (20% basal area removed) (11.8 m^2/ha; 18%) was higher than that of thinning alone or fertilizing alone. The response was not affected by additional fertilizer; however, the response increased with increase in percent basal area removed.
- The relationships of fertilization, thinning, and combined fertilization and thinning responses to initial stand age and site index were weak or could not be detected. Other factors may have confounded these relationships.

The results from this study confirm that thinning and fertilizing with N can accelerate stand suitability for harvest by boosting growth in closed canopy immature stands of western hemlock on northern Vancouver Island. Additional site-specific research should be conducted to help the forest manager identify those western hemlock sites which can respond well to fertilization.

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APPENDIX 1: Response equations for the stand and prime trees

Hemlock Equation Coefficient Definitions

AGE ..... Actual age of stand in years = IAGE + INT
AGEBA ..... IAGE • INITBA
AGECBA ..... IAGE • IBACROP
AGEPBA ..... IAGE • PRELBA
ANGROWTH ..... Annual Growth of stand (m^2/ha/yr) = COGROWTH + ANNRESP
ANNRESP ..... Annual response of treated stands (m^2/ha/yr)
ARELRESP ..... Annual relative response (%) = ANNRESP/COGROWTH) •100%
BR ..... Basal area reduction factor = (PRELBA-INITBA)/INITBA
COGROWTH ..... Annual growth of control stand (m^2/ha/yr)
CONYIELD ..... Cumulative yield of control stand (m^2/ha)
CUMRESP ..... Cumulative response of treated stands (m^2/ha)
FA ..... Fertilization amount (0,225,450,675 and 900 kg N /ha)
IAGE ..... Initial age of stand (years)
IBACROP ..... Initial basal area of prime trees (m^2/ha)
INT ..... Interval year of measurement (0,3,6 and 9 years)
INTCBD ..... Interval cubed = $(INT)^3$
INTSQ ..... Interval squared = $(INT)^2$
INITBA ..... Initial basal area of entire stand (m^2/ha)
INITSTEM ..... Initial number of trees in treated stand (# stems/ha)
LNBR ..... Natural logarithm of BR
LNPSTEM ..... Natural logarithm of PRELSTEM
K ..... Constant to avoid computing logarithms of negatives
PBAPLOT ..... Preliminary basal area of entire stand (m^2/ha)
PRELBA ..... Same as PBAPLOT
PRELBASQ ..... PRELBA squared = $(PRELBA)^2$
PRELSTEM ..... Preliminary number of trees in stand (# stems/ha)
RELRESP ..... Relative cumulative response (%) = (CUMRESP/CONYIELD)•100%
SITE ..... Site index of stand (Hegyi m @ 50 years)
SITEAGE ..... Site index • Initial age = (SITE•IAGE)
T0F0 ..... Treatment category for control stands
T0F1-4 ..... Treatment category for unthinned, fertilized stands
T1-3F0 ..... Treatment category for thinned, unfertilized stands
T1-3F1-4 ..... Treatment category for thinned, fertilized stands

APPENDIX 1: Continued

HEMLOCK ANALYSIS: RESPONSE EQUATIONS

CUMULATIVE ABSOLUTE PREDICTED RESPONSE > $CUMRESP = [e^{(CO+C1 \cdot INT)} \cdot (INT)^{C2}] - K$

ANNUAL ABSOLUTE PREDICTED RESPONSE > $ANNRESP = e^{CO} \cdot [e^{(C1 \cdot INT)} \cdot (C2 \cdot (INT^{(C2-1)} + INT^{C2}) \cdot C1 \cdot (e^{(C1 \cdot INT)})]$

CUMULATIVE RELATIVE RESPONSE > RELRESP = (PREDRESP/YIELD) •100%

ANNUAL RELATIVE RESPONSE > ARELRESP = (ANNRESP/ANGROWTH)•100%

PREDICTED CUMULATIVE YIELD > YIELD = CONYIELD-(PREDYLD•BR) + PREDRESP

ANNUAL GROWTH > ANGROWTH = COGROWTH + ANNRESP

HEMLOCK: ENTIRE STAND COEFFICIENTS

T0F0: Control Equations and Coefficients

CUMULATIVE CONTROL YIELD > CONYIELD = B0 + (B1•INTSQ) + (B2•INTCBD)

ANNUAL CONTROL GROWTH > COGROWTH= (2•B1•INT) + (3•B2•INTSQ)

B0 = 0.390877+(1.003534•PRELBA)

B1 = 3.004429-(0.022041•IAGE)-(0.237432•LNPSTEM)

B2 = 0.095260+(0.001458•IAGE)+(0.000005497•PRELSTEM)

T0F1-4: No Thinning: All Fertilization Levels

C0 = 3.763610-(0.007119•PRELBA)-(0.000019839•FA)-(0.013033•IAGE)
+(0.000145•AGEPBA)+(111.532049/PRELSTEM)

C1 = 0.572991+(0.007229•PRELBA)+(0.000017001)•(0.013268•IAGE)
-(0.000147•EAGEPBA)-(115.828703/PRELSTEM)

C2 = 2.097388-(0.060750•PRELBA)+(0.000442•PRELBASQ)

K = 25

T1-3F0: All Thinning: No Fertilization

C0 = 2.995813-(0.004435•PRELBA)-(0.040399•LnBR)-(0.074603•LnPSTEM)

C1 = -1.586092+(0.021541•IAGE)+(0.026650•SITE)-(0.000618•SITEAGE)
+(0.094366•LnPSTEM)

C2 = 0.008672-(0.000117•PRELBASQ)+(0.000155•AGEPBA)

K = 10

T1-3F1-4: All Thinning and All Fertilization Levels

C0 = 2.885272-(0.071397•LnBR)(0.000003654•FA)-(0.000054873•AGEBA)
-(0.087953•LnPSTEM)

C1 = 1.627585+(0.030146•LnBR)-(0.000003036•FA)+(0.016492•IAGE)
+(0.021950•SITE)-(0.000426•SITEAGE)+(0.119299•LnPSTEM)

C2 = 2.314192-(0.042474•IAGE)-(0.078743•SITE)+(0.001421•SITEAGE)

K = 10

APPENDIX 1: Continued

HEMLOCK: PRIME TREES COEFFICIENTS

T0F0: Control

B0 = 0.275366+(1.016619•IBACROP)-0.000354•SITEAGE)

B1 = 0.024625+(0.007733•IBACROP)+(0.004333•PBAPLOT)-(0.000111•AGEPBA)

B2 = -0.001731-(0.000666•IBACROP)-(0.000773•SITE)+(0.000022023•SITEAGE)

T0F1-4: No Thinning: All Fertilization Levels

C0 = 2.080911+(0.000145•PBAPLTSQ)-(0.000010789•FA)-(0.041702•SITE)
+(0.001273•SITEAGE)-(0.000520•AGEPBA)

C1 = -0.54582+(0.000020048•FA)-(0.000374•SITEAGE)+(0.000127•AGEPBA)

C2 = -0.015040-(0.000077732•FA+(0.000776•SITEAGE)-(0.000256•AGEPBA)

K = 5

T1-3F0: All Thinning: No Fertilization

C0 = 1.733052-(0.002790•PBAPLOT)-(0.193307•BR)+(0.000021033•AGEPBA)

C1 = -0.186046+(0.002934•IBAPLOT)+(0.379036•BR)-(0.000013415•AGEPBA)

C2 = 0.137331+(0.006958•IBACROP)-(0.009501•SITE)

K = 5

T1-3F1-4: All Thinning and All Fertilization Levels

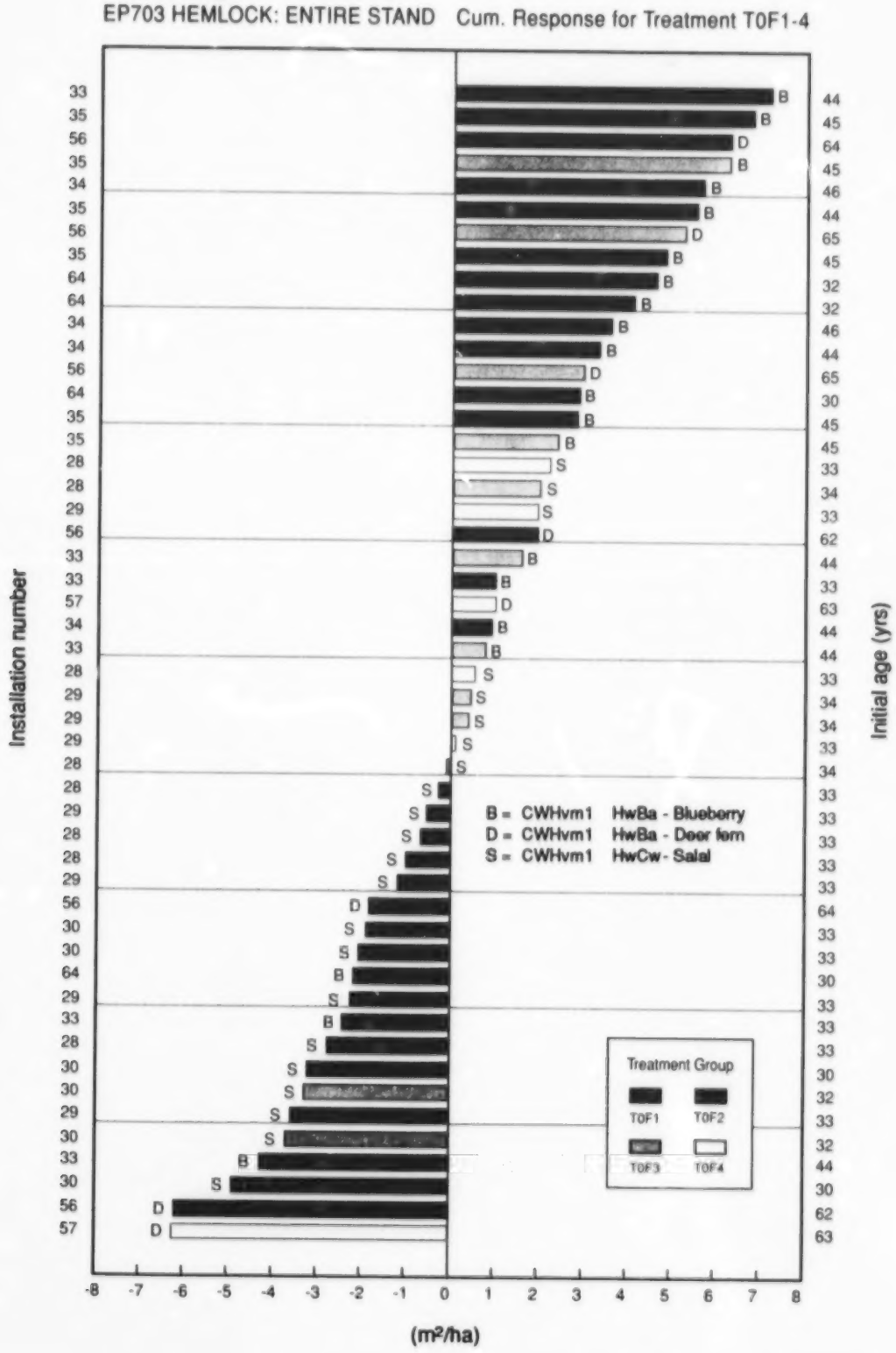
C0 = 1.822681+(0.000067387•PBAPLTSQ)(0.000009389•FA)-(0.104018•BR)
-(0.020932•SITE)+(0.000659•SITEAGE)-(0.000261•AGEPBA)

C1 = -0.200958-(0.000060763•PBAPLTSQ)-(0.000009456•FA)
+(0.018657•SITE)-(0.000578•SITEAGE)+(0.000234•AGEPBA)

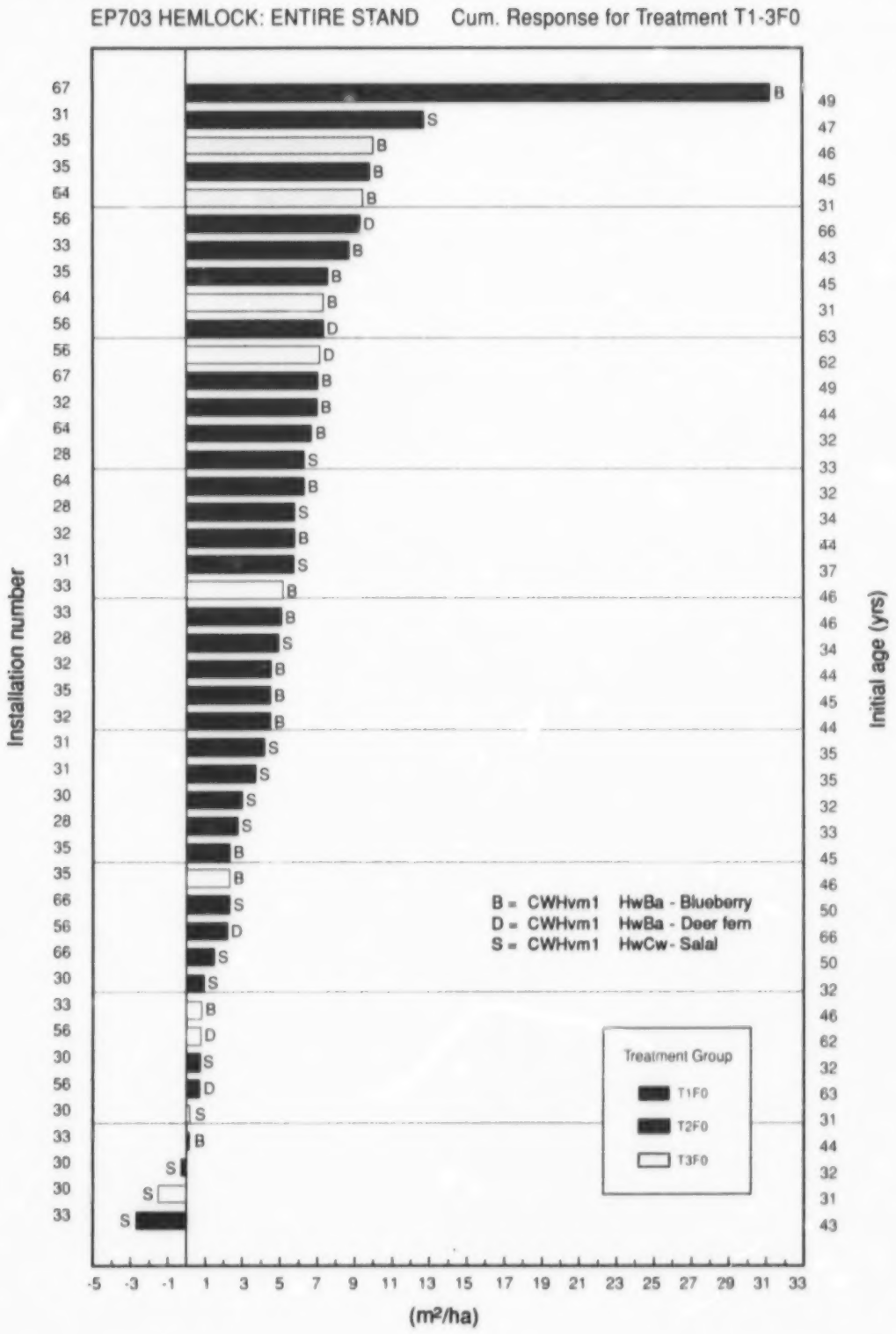
C2 = 1.622347+(0.028602•IBACROP)-(0.029561•IAGE)-(0.076336•SITE)
+(0.001744•SITEAGE)-(0.000129•AGEPBA)-(0.000489•AGECBA)

K = 5

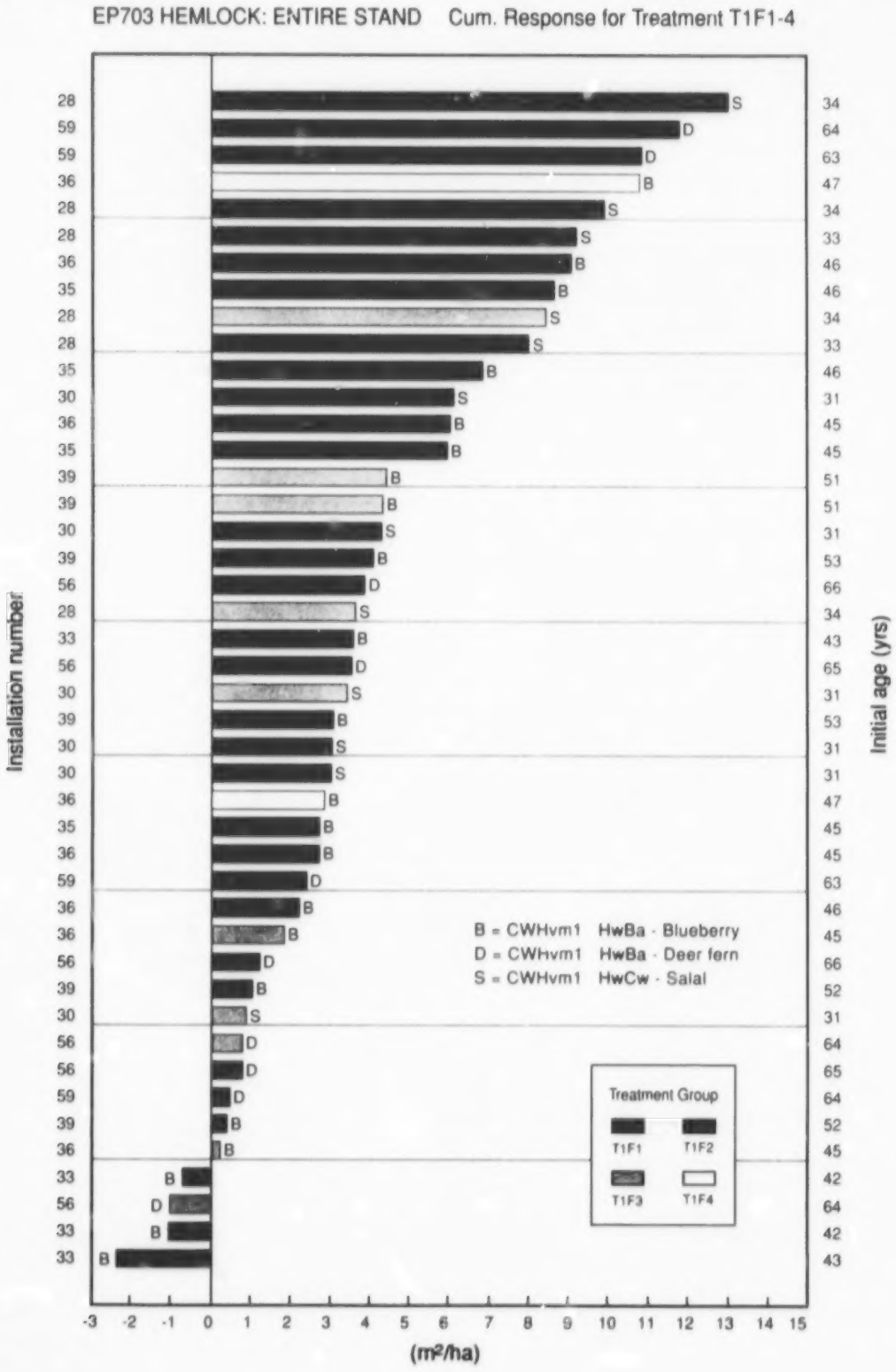
APPENDIX 2. Predicted cumulative stand response by site unit, treatment, and initial age


EP703 HEMLOCK: ENTIRE STAND Cum. Response for Treatment T0F1-4
Installation number
Initial age (yrs)
B = CWHvm1 HwBa - Blueberry
D = CWHvm1 HwBa - Deer fern
S = CWHvm1 HwCw - Salal
Treatment Group
T0F1
T0F2
T0F3
T0F4
-8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8
(m²/ha)

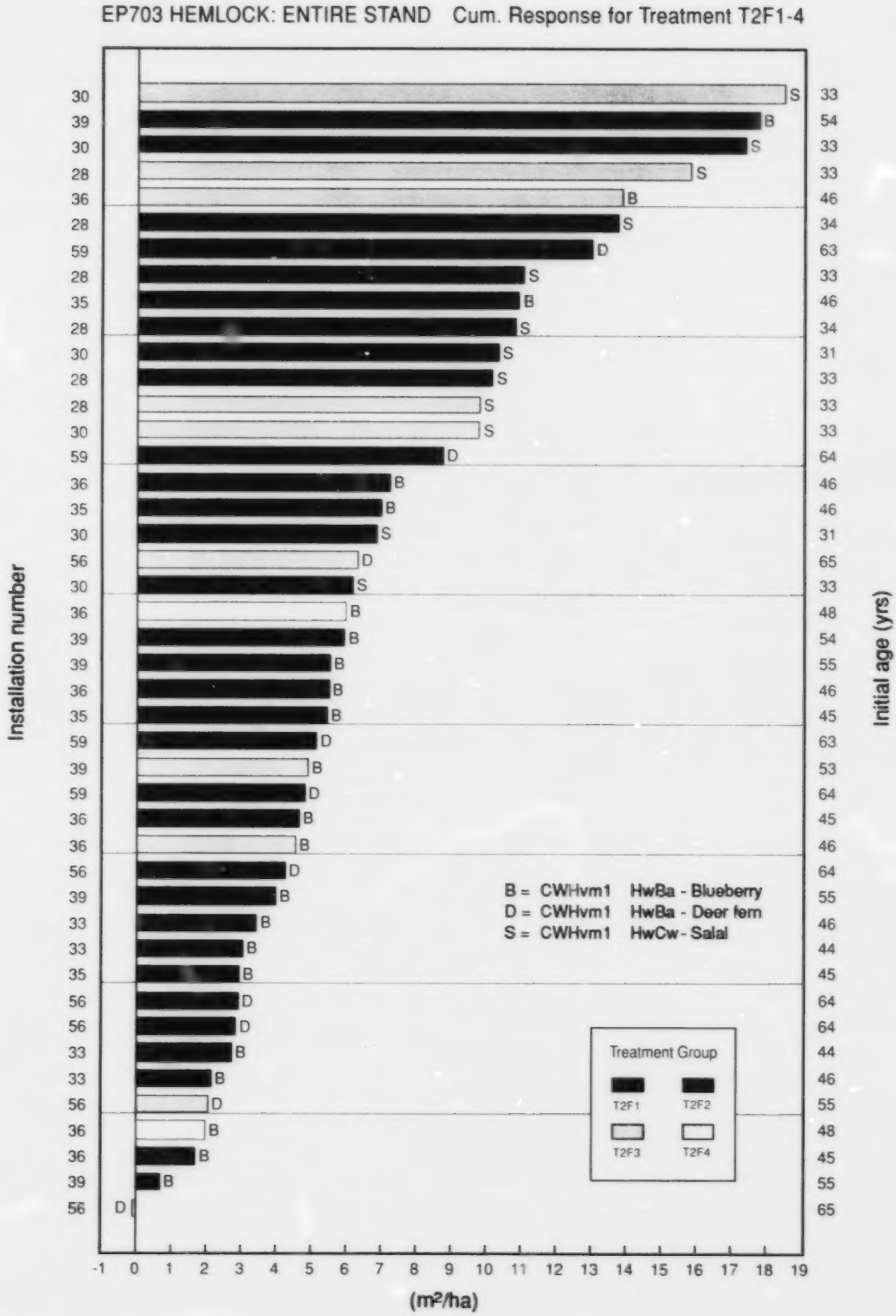
APPENDIX 2: Continued



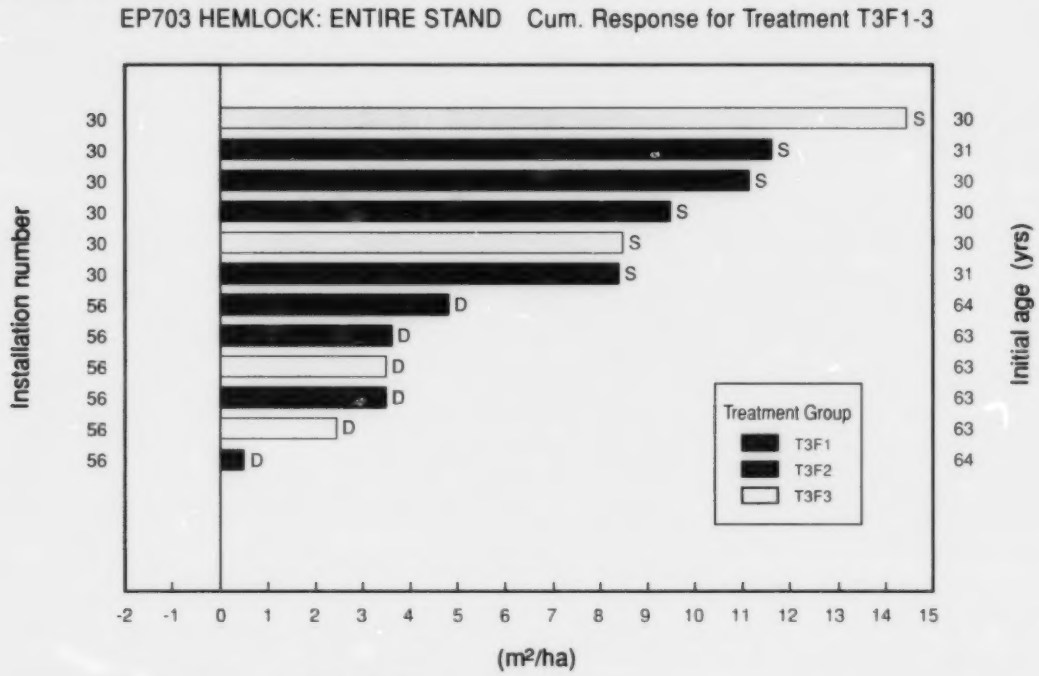
APPENDIX 2: Continued



APPENDIX 2: Continued



APPENDIX 2: Continued


EP703 HEMLOCK: ENTIRE STAND Cum. Response for Treatment T3F1-3
Installation number
Initial age (yrs)
30 30 30 30 30 30 56 56 56 56 56 56
30 31 30 30 30 31 64 63 63 63 63 64
S S S S S S D D D D D D
Treatment Group
T3F1
T3F2
T3F3
-2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
(m²/ha)

B = CWHvm1 HwBa - Blueberry
D = CWHvm1 HwBa - Deer fern
S = CWHvm1 HwCw - Salal

STAND ATTRIBUTES BY INSTALLATION FOR BAR GRAPHS

Inst.	Age (yrs)	Site index (m)*	Ba (m²/ha)	Site unit
28	42.0	28.5	69.789	CWHvm1 HwCw - Salal
29	42.0	26.5	71.460	CWHvm1 HwCw - Salal
30	41.5	24.5	69.329	CWHvm1 HwCw - Salal
31	44.0	26.5	60.159	CWHvm1 HwCw - Salal
32	52.5	28.5	55.832	CWHvm1 HwBa - Blueberry
33	52.0	28.5	76.370	CWHvm1 HwBa - Blueberry
34	53.0	25.5	68.506	CWHvm1 HwBa - Blueberry
35	53.5	24.0	76.277	CWHvm1 HwBa - Blueberry
36	54.0	27.5	64.896	CWHvm1 HwBa - Blueberry
39	60.5	30.5	55.482	CWHvm1 HwBa - Blueberry
56	73.0	31.5	56.819	CWHvm1 HwBa - Deer Fern
57	71.5	32.5	86.823	CWHvm1 HwBa - Deer Fern
59	71.5	31.0	63.054	CWHvm1 HwBa - Deer Fern
64	39.0	24.0	54.395	CWHvm1 HwBa - Blueberry
66	58.5	29.0	54.959	CWHvm1 HwCw - Salal
67	58.0	23.5	57.383	CWHvm1 HwBa - Blueberry

58 - deleted due to windblown damage

* Based on 50 years total age and the site curves of Hegyi *et al.* (1979).